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Multi-axial Geogrid Stabilized Working Platform for Ringer Crane Operation

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ABSTRACT
Design and construction of a geogrid stabilized working platform for use with a ringer crane in the US was undertaken in 2016 and completed in 2017. The ringer crane was configured with a maximum bearing pressure of 192 kPa, a load spreader ring with outside and inside diameters 56 m and 33.2 m, respectively, and was rated the third largest in the world. Stringent criteria for differential and total settlement needed to be met to ensure successful crane operation. Site conditions exhibited predominantly fat clays and occasional sandy silt lenses. A geogrid stabilized working platform was designed to improve allowable bearing capacity of the soil and to decrease potential settlement. Estimated total cost savings of $3.1 million when compared with original plans to construct a deep foundation system. Success of the geogrid stabilized platform was further demonstrated when it withstood Hurricane Harvey without damage and the crane was back in operation the day after the storm passed.

RÉSUMÉ
La conception et la construction d'une plateforme de travail stabilisée par des géogrilles aux États-Unis pour son usage avec une grue du type Ringer ont commencé en 2016 et finis en 2017. La grue Ringer qui a été classé le troisième plus grand au monde, a été configurée avec une pression d'appui maximale de 192 kPa, un anneau répartiteur de charge avec des diamètres extérieur et intérieur 56 m et 33,2 m respectivement. Des stricts critères pour les tassements différentiels et totaux devaient être respectés pour assurer le bon fonctionnement de la grue. Les conditions du site présentaient principalement des argiles plastiques avec des traces occasionnelles de silt sableux. Une plateforme de travail stabilisée par des géogrilles a été conçue pour améliorer la capacité portante admissible du sol et pour réduire les tassements potentiels. Des économies totales estimées de 3,1 millions de dollars par rapport aux plans originaux de construction d'un système de fondation profonde. Le succès de la plateforme stabilisée par des géogrilles a été démontré davantage lorsqu'elle a résisté à l'ouragan Harvey sans dommage et que la grue a été remise en service le lendemain du passage de la tempête.

1 INTRODUCTION

Many construction projects invariably require working platforms to support cranes over soft subgrades. Platforms of this type are generally considered to be temporary works, often with little or no site investigation, and designed to ensure safe operating conditions for the heavy machinery that will be supported. Inadequate design of such working platforms can result in poor working conditions, such that frequent re-filling or re-grading may be required with associated delays. In severe cases, heavy machinery may become unstable resulting in collapse or overturning of the machinery. These accidents frequently result in injuries or fatalities, and lengthy investigations may result, including detailed scrutiny of soil data, loadings and the design method used to dimension the platform.

Generally, working platforms are built using well graded granular fills that are often expensive especially when very heavy loads are to be supported and the platforms become very thick. An increasingly popular way to reduce platform thickness is by incorporating geosynthetics, and particularly polymer geogrids in the platform design.

1.1 Mechanical Stabilization

Mechanical stabilization takes place when aggregate or soil particles interlock with the apertures of a stiff geogrid, resulting in confinement of the particles as illustrated in Figure 1. When a stiff geogrid develops this interlocking mechanism, significant benefits result in terms of the mechanical performance of the composite layer and load transfer to the underlying soil. The benefits of the geogrid composite layer will manifest very small surface deformation, implying very small deformation of the geogrid itself. Mechanical stabilization of working platforms results in increased ground bearing capacity and reduced settlement at working load; these conclusions have been verified by full-scale load tests with continual on-going verification.

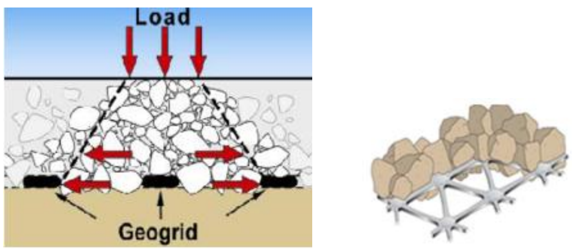


Figure 1. Mechanical stabilization and interlocking mechanism with geogrid

2 PROJECT BACKGROUND

The project described in this paper was to construct a petrochemical facility in southwest Louisiana in the Lake Charles area near Calcasieu Parish. The 250-acre proposed development involved new construction of a $1.9 billion ethane cracker complex and a $1.1 billion mono-ethylene glycol (MEG) plant. Construction of both plants was undertaken in 2016. Due to extremely heavy lifts to be made during construction of these plants and complicated by very limited operating space available, the use of a specialized ringer crane was required. Construction was completed over the next several years and both plants opened in 2019.

2.1 Ringer Crane

Mammoet Fabrication B.V. designed and manufactured the PTC-200 DS ringer crane to be used for construction of the petrochemical facility. The ringer crane was configured with a maximum bearing pressure of 192 kPa, a load spreader ring with outside and inside diameters of 56 m and 33.2 m, respectively, and was rated the third largest ringer crane in the world. The crane capacity was 9578 kN at a 74-m lift radius. Figure 2 shows a photo of a typical PTC ringer crane; the crane footprint rides on a circular track system called twin ring beams that form a stable A-frame. To ensure successful operation of the crane, rigorously exacting criteria for total settlement and more importantly, differential settlement need to be met.

Figure 2. Photo of a PTC ringer crane

2.1.1 Foundation Levelness Criteria

Operational requirements for the massive ringer crane included stringent settlement criteria. Elevation of the crane foundation on which rests the circular track system, and transcribed as the overall slope of the foundation, could not vary more than 10% over the 56 m diameter of the outside ring which translates to less than 0.06 degree. Micro levelness affects the distribution of pressure on the load spreaders and rail girders; dictating that the soil needs to be smooth (a sand-like surface) without lumps or rocks and elevational variances must be less than 0.29 degree. Meso levelness affects the individual levelness of the load spreaders, bogies and upper structure; levelness cannot vary more than 10 mm over any 5 m rail distance or 2 mm over the 11.4 m length of rail mat. Macro levelness affects the overall levelness of the load spreaders, rails, and boom systems; required levelness of adjacent load spreaders must be within 15 mm over a 15 m distance between the base frames.

2.2 Site Conditions

Site investigation included numerous SPT borings and CPT testing locations that were in the vicinity of structures and their respective foundations. However only one SPT boring was made in the proposed working platform area. Problematic soil conditions were found at the crane pad area and consisted of fat clays that were oftentimes slickensided, and occasional sandy silt lenses and pockets. The vertical soil profile showed five different CH layers comprising nearly 50% of the soils in the 30.5 m depth of SPT exploration. Further complicating the soil conditions, a fluctuating water table between -1.83 m and -1.22 m was found and created perched conditions within the clay soil. Unconsolidated-undrained test results indicated clay strength of around 32 kPa.

3 ORIGINAL WORKING PLATFORM DESIGN - DEEP FOUNDATION SYSTEM

Original plans for the crane bearing pad were to construct a deep foundation system composed of two hundred 457-mm square concrete piles driven to a depth of 19.8 m and with a 61-m diameter concrete pile cap. Estimated total cost for the deep foundation system was $2.7 million without the cost of potential overruns. The pile cap could remain in place after the crane operation was complete or it could be demolished for an additional cost of $600,000; bringing the estimated total cost of the deep foundation system to at least $3.3 million.

4 ALTERNATE GEOGRID STABILIZED WORKING PLATFORM DESIGN

The LA MEG 1 Project Team requested an alternative platform be designed that would be less expensive and more convenient to support the massive ringer crane needed for construction of the plants. A consultatory effort between CBI, Tensar International and LA MEG 1 Project Team worked to produce a multi-axial geogrid stabilized platform design. Requirements for the working platform included the capability to support a ground bearing pressure of 295 kPa, have a subgrade stiffness greater than 6.5 kg/cm^3, and maintain differential settlements of less than 1:100.

The geogrid and stone fill layers of the working platform design would act as a composite material and effectively stabilize the soft soil by aggregate interlock. The geogrid stabilized platform would provide the added benefit of lateral confinement and an effective increase in soil strength for the stone layers above the geogrid layer elevations.

4.1 Materials

Crushed angular graded aggregate (LA-610 Class A-1 road base material) compacted to 98% Modified Proctor was used. The particle size distribution for the aggregate is shown in Figure 3. The aggregate properties included maximum dry density 21.5 kN/m^3, rodded unit weight 17.6 kN/m^3, loose unit weight 16.2 kN/m^3, optimum moisture 7.25%, LA abrasion 22, and sulfate soundness 0.4.

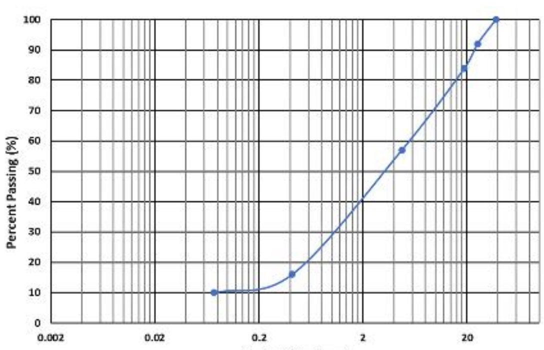


Figure 3. Aggregate particle size distribution

The multi-axial geogrid was Tensar TX160™ and an 8 oz. needle punched nonwoven geotextile (Mirafi S800) was used as a separator to prevent migration of fine particles between the base aggregate course and the sand leveling course used to meet the micro levelness requirement for the crane operation.

4.2 Multi-axial Geogrid Working Platform Design

The platform designed was 1.83 m thick with 5 layers of multi-axial geogrid. Over-excavation of the footprint was necessary to ensure the pad would be constructed with at least 1900 mm of compacted structural fill thickness with the geogrid layers. Excavation limits were approximately 71,830 mm to 62,700 mm, and the load spreader extents were 27,986 mm to 16,582 mm, outside to inside radii, respectively. The geogrid annulus extent was 17,501 mm. A schematic representation of the crane platform extents is shown in Figure 4. The excavated base was required to be proof-rolled and any soft areas encountered needed to be over-excavated, re-filled with structural fill material, and compacted again.

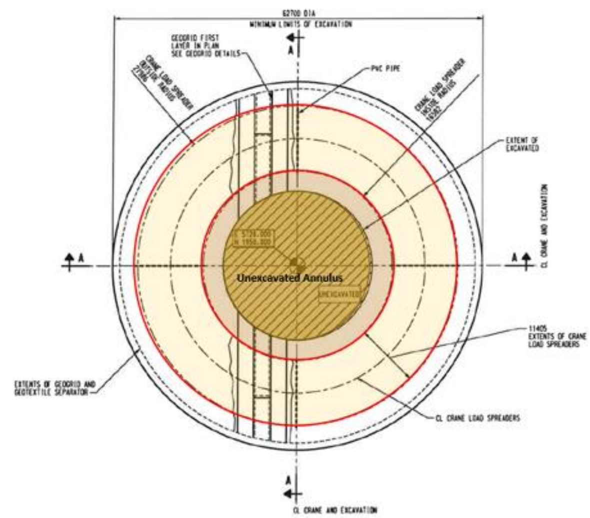


Figure 4. Crane platform extents

The multi-axial geogrid overlap was 305 mm end-to-end and side-to-side. The seam direction of the successive geogrid layers was rotated 60 degrees from the seam direction of the previous layer, so the seam direction of each geogrid layer did not align with previous layers. The schematic seam arrangement for multiple geogrid layers is shown in Figure 5.

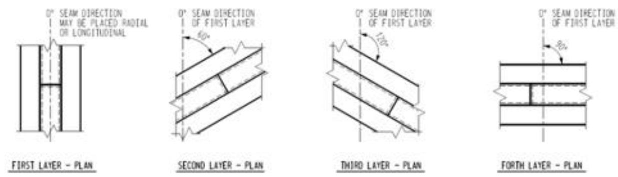


Figure 5. Directional orientation of successive geogrid layers

4.3 QA / QC Requirements

Proof-rolling was performed with an off-road loaded dump truck. Pumping occurred in the excavation in several soft areas along a previous drainage ditch that traversed the working platform location. These pumping areas were over-excavated an additional 305 mm and then lined with geogrid prior to backfilling with structural fill and compacting. In-situ density testing was conducted in these areas and materials met specifications to continue construction.

The aggregate and geogrid layer thicknesses of the platform are presented in Figure 6. Plate load tests based on specifications for this project were performed on lift three prior to placement of the geogrid in early April 2017 and provided a measure of quality control during construction of the platform. One test was conducted every 60 degrees at a radius of 22.8 m from the centerline of the platform and corresponds with the centerline of the load spreaders. To conduct the tests, a 457-mm diameter steel plate was used with a 227 kN hydraulic jack and a loaded dump truck provided the reaction force. Loads were applied in three increments of 165.2, 342.3, and 550.6 kPa and held for appropriate time intervals. Final readings were taken five minutes after the ultimate load was removed for recovery behavior. Ground stiffness values were calculated at each location and confirmed stiffness was greater than the 6.5 kg/cm^3 required for the platform area. Quality control continued with compaction and moisture testing being performed on lift five prior to placement of the geogrid.

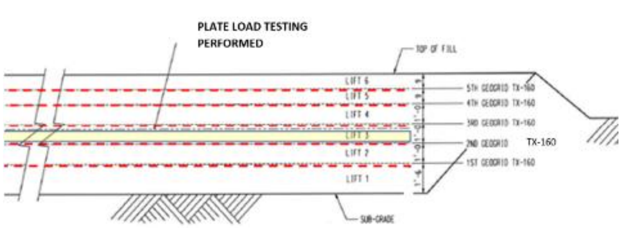


Figure 6. Layer profile for aggregate and geogrid in the stabilized platform

Drainage needed to be provided for the platform ring and provision for electrical connections in the unexcavated center of the ring annulus. Drainage culverts consisting of PVC pipe were placed under the sand bed from the inside of the ring to outside the ring and denoted as D1, D2, D3, and D4 as shown in Figure 7. A detail of a culvert drainage pipe is shown in Figure 8. These culvert pipes were connected to 4 sump pumps located inside the unexcavated ring to collect water from the center and remove any ponded water within the footprint to beyond the ring area, as seen in plan and profile in Figure 9. A 100 mm PVC pipe was used to convey electrical power supply lines to the center of the ring pad and located below the sand bed.

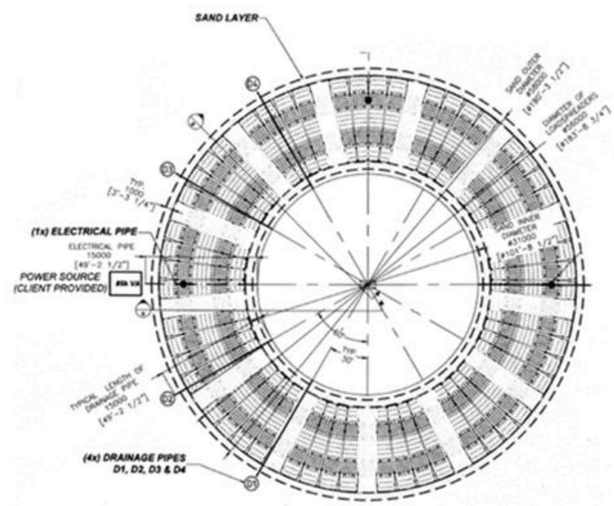


Figure 7. Plan view of drainage design

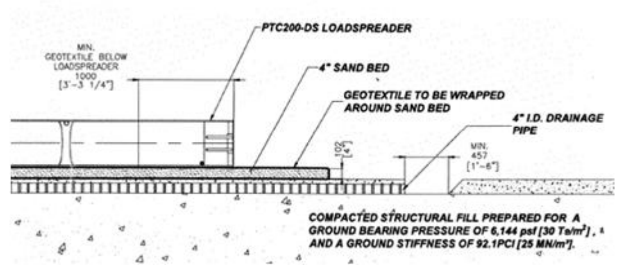
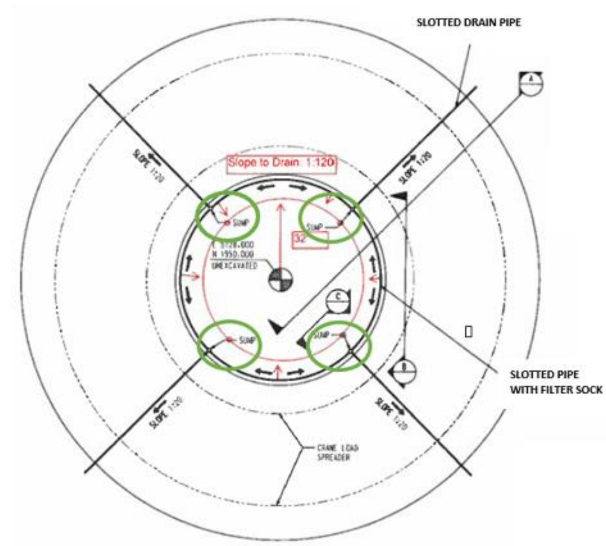


Figure 8. Detail of drainage pipe area



Note: Sump pump locations (noted in green)

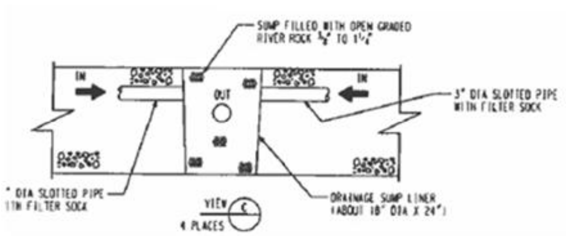


Figure 9. Plan and profile of four sump pump locations and connection system

A stable roadway sand bed 100 mm thick was placed on top of the sixth or uppermost layer of structural fill. The sand layer was to help in providing micro levelness for the crane to assure uniform distribution of pressure to the load spreaders and rail girders during crane operation. Construction criteria included the geotextile separator must be folded back 2 to 3 m at the inside and the outside of the bed, creating a sand pontoon cushion, as shown in Figure 10. In addition, the load spreaders must overlap at least 1 m of the geotextile separator to prevent sand from sliding outward and washing away during heavy rain or blowing away by strong wind.

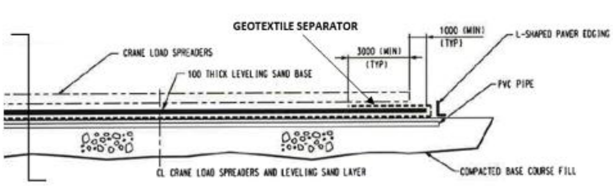


Figure 10. Details of sand layer leveling bed

4.4 Estimated Settlement

Settlement analyses were conducted with software that used two somewhat different methods due to inherent limitations of the software available at the time. Dimension Solution software or DSS (Tensar International Corporation) was used to estimate the primary settlement below the centerline of a geogrid stabilized area. DSS software is capable of estimating geogrid stabilized foundation settlement using the Westergaard methodology, as well as, unstabilized foundation settlement by Boussinesq methods. SetCalc software (Yang and Duncan) was also used to estimate primary differential settlement of the same geogrid stabilized area because it has the capability to provide estimates of primary settlement below any given point for a distributed applied load, and therefore allow calculation of differential settlement from point to point.

Using a preconsolidation pressure of 167.6 kPa, settlement was estimated for two cases of applied bearing pressure, 191.6 kPa and 179.9 kPa. Both a geogrid stabilized platform and an unstabilized platform were analyzed for comparative purposes of the benefit provided by the geogrid. For all cases, a pseudo rectangular area 11.58 m by 24.38 m was assumed to model the crane footprint wheel positions on the load spreader track ring. Illustrated in Figure 11 are the three positions used to estimate differential settlement relative to the center point of the pseudo rectangular area. DSS results represent estimated settlement at the centerline of the pseudo rectangular area for both reinforced and unreinforced conditions. SetCalc results represent estimated settlement for four different points of the pseudo rectangular area; namely corner, midpoint short side (MPSS), midpoint long side (MPLS), and centerline of the rectangularly loaded area.

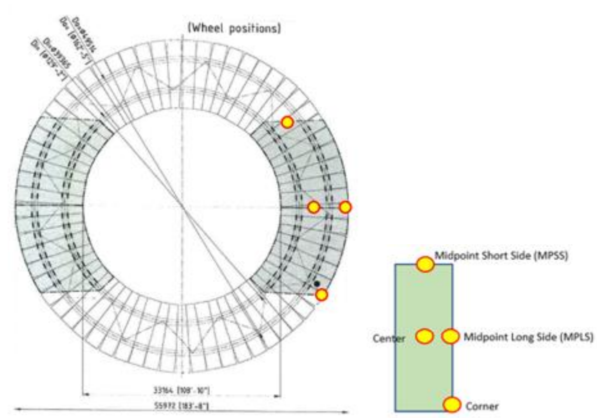


Figure 11. Representation of pseudo rectangular area and corresponding points of model used for analyses

Shown in Figure 12 is the plotted results from DSS and SetCalc settlement analyses with depth and assuming 191.6 kPa applied bearing pressure; the soil profile is symbolically noted to the right of the graph. As indicated, there were five different CH layers that composed nearly 50% of the vertical soil profile. For analyses purposes, a 167.6 kPa preconsolidation pressure was assumed to a depth of 12.2 m followed by a constant OCR of 1.8 to 30.5 m. Load redistribution was modeled as 191.6 kPa through the geogrid stabilized platform to the depth of 1.8 m and then 105.3 kPa applied bearing pressure below.

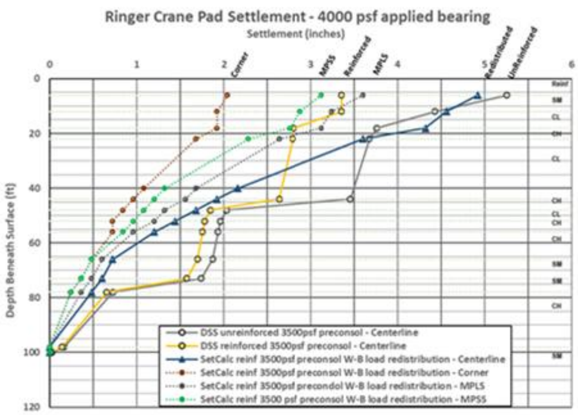


Figure 12. Results of settlement analyses with depth

As expected, predicted results using different methods of analyses can vary considerably due to assumptions and inherent limitations of different methodologies and numerical solvers used in software calculations. A summary of the calculated results at the four different rectangular points for the applied bearing pressures of 191.6 kPa and 179.9 kPa are shown in Table 1. Using the percentage of settlement for each of the three points relative to the center point as determined from the SetCalc analyses, the DSS calculated settlement for the center point was used to proportionately estimate the amount of settlement in mm at the other three points of the pseudo rectangular area as a percentage of the settlement at the center point. Not surprisingly, the geogrid stabilized pad showed less primary estimated settlement than the unstabilized pad for the cases analyzed. Note, the calculations are based on the assumption that the estimated settlement distribution due to the location of the point of interest relative to the center of the pseudo rectangular area of the geogrid stabilized pad will be very similar to that of the unstabilized pad.

Table 1. Estimated primary settlement of crane platform

	SetCalc Results		DSS Results	
Applied Bearing Pressure 179.9 kPa				
Area Location	Total Settlement (mm)	% of Center	Total Settlement (mm)	Proportion of Similar Settlement (mm)
Center	121.9	100	75.7	75.7
MPLS[(1)]	85.3	70	-	53.1
MPSS[(2)]	76.2	62.5	-	47.2
Corner	48.8	40	-	30.2
Applied Bearing Pressure 191.6 kPa				
Center	125	100	85.3	85.3
MPLS[(1)]	91.4	73.2	-	62.5
MPSS[(2)]	79.3	63.4	-	54.1
Corner	51.8	41.5	-	35.3

[(1)]Midpoint long side
[(2)]Midpoint short side

Measured settlements were expected to be less than the estimated values due to the relatively short service period that the ringer crane would be on site. Estimated total primary settlements would be assumed to occur over a relatively long time period based on the soil profile and applied loading.

Shown in Table 2 are the overall averages of combined values from both DSS and SetCalc settlement analyses to summarize estimates of the differential settlement in mm and proportion (%) of the center point total settlement. Calculations were based on the assumption that differential settlement is relative to the amount of total settlement estimated and settlement is uniform over the entire area of the ringer crane platform.

Table 2. Overall average estimated settlements

Applied Bearing Pressure 191.6 kPa			
Area Location	Total Settlement (mm)	Differential Settlement (mm)	Proportion % of Center
Center	104	-	100
MPLS[(1)]	76	28	30
MPSS[(2)]	66	38	40
Corner	43	61	60

[(1)]Midpoint long side
[(2)]Midpoint short side

5 CONSTRUCTION AND CRANE OPERATION

By June 2017, the geogrid stabilized working platform was completed and fully operational. The ringer crane platform was installed on time, in spite of numerous construction delays due to heavy seasonal rains. Constructing the platform with an interior drainage system to prevent ponding rainwater within the footprint was key to avoiding operational delays. Based on seasonal weather during on-going scheduled construction, typical rainfall events were expected to occur when the crane was performing heavy lifts for construction of the petrochemical facility. However, national weather added an unexpected major challenge

Figure 13. On site photo of wash tower lift with PTC-200 DS ringer crane (courtesy of Mammoet Fabrication B.V.)

when Hurricane Harvey traveled up the gulf coastline and made landfall mid-August 2017 during the timeline that the crane was scheduled to perform several of the heaviest lifts. Notwithstanding the torrential winds and rain, the geogrid stabilized crane platform withstood the severe storm without damage, and the day after Hurricane Harvey passed the crane resumed operation and construction continued. The success of the geogrid stabilized crane pad performance in this major tropical storm was attributed to the specialized drainage system that allowed storm water to quickly drain and the geogrid system that maintained lateral confinement to prevent soil migration and maintained bearing capacity of the underlying soil. Shown in Figure 13 is a photo of the actual PTC-200 crane performing an on site lift of a wash tower that was 100 m tall and weighed 688 metric ton.

5.1 Actual Settlement

Mammoet carefully monitored the various elevational levelness criteria of the platform to assess any differential settlement throughout the timeline the ringer crane was in operation. Monitoring included measuring elevational changes for levelness of the load spreaders (micro-levelness), rail in-out (meso-levelness), base frame front (macro-levelness), and overall slope (front-rear) of the crane before, during and after each lift and also before, during and after positioning of the counterweights. If any change in elevation was found based on the measurements, the crane would not be permitted to operate until some remedial measures would be taken to assure levelness of the foundation platform. If necessary, Mammoet would have requested and designated excavation and replacement of the crane platform before resuming operation.

A summary of the results from the settlement monitoring performed by Mammoet is shown in Table 3 and indicate no concerns regarding differential settlement had occurred. Mammoet summarized that the geogrid stabilized crane platform drained extremely well and had zero settlement issues, and in fact, this crane platform design had even exceeded the performance of their own crane platform designs. Mammoet went on to say that they were planning on utilizing a similar design on future projects and referred to this design as the new “gold” standard for their PTC cranes.

Table 3. Settlement monitoring results

Levelness Criteria	Maximum Limit (mm)	Actual Measured (mm)
Overall (front-rear)	56	5
Micro (load spreaders)	10	4
Meso (rail in-out)	25	2
Macro (base frame front)	53	4

5.2 Budgetary Considerations

The geogrid stabilized crane platform was installed within budget. The installed cost of the geogrid crane platform was just slightly over $1 million. The crushed stone used with the geogrid layers was easily removed from the crane operational location and reused as structural fill at other locations on site. As previously presented, the original deep foundation system of concrete piles with a concrete cap (and removal thereof) was at an estimated total cost of $3.3 million. Accordingly, the geogrid stabilized crane platform resulted in a cost savings of $2.3 million, plus an additional cost savings of $815,000 in crane fees. The crane lifts were completed 32 days ahead of schedule due to the geogrid stabilized platform being constructed on time. A total savings of $3.11 million was realized by using the geogrid stabilized crane platform instead of the original deep foundation system for this project.

6 LESSONS LEARNED AND PRIMARY REASONS FOR SUCCESS

Case studies are instrumental in sharing experiences to promote learning by project successes, as well as, learning from those projects not-quite so successful. A case study has been presented that illustrates a consultatory effort to design a multi-axial geogrid stabilized working platform for a massive heavy lift PTC-200 ringer crane. This design provided an alternative to an expensive deep foundation system of concrete piles. Concerns regarding settlement were paramount to the design and stringent differential settlement criteria needed to be met. Due to inherent limitations of software capabilities, a somewhat unconventional approach to interpreting software analyses and estimating differential settlement was used. Continual monitoring of the platform levelness in-service was conducted to ensure successful operation of the crane. In comparison to the actual measured deformations of the platform, the calculated total settlements were conservative, as well as the estimated differential settlements. Drainage of the ring footprint was also a concern with undesirable potential ponding effects, and further compounded by the problematic soil conditions on site. Accordingly, the importance of adequate drainage provisions was emphasized and designed appropriately.

The primary reasons for the huge success of this project may be attributed to some combination of the following. First, direct involvement from the very beginning between the owner, geotechnical engineers, consultants, geogrid manufacturer, and crane fabricator. Second, open communications were maintained between all the parties involved and at all steps during construction. Third, and perhaps most importantly, the willingness of the owner and their engineers to be open to alternative designs. All three of these reasons contributed to the great success of this project and should be viewed as exemplary toward the success of future projects.

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